

## Plankton Distribution on the Agulhas Bank Between 20°E & 22°E Long.

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Monthly plankton samples taken with the Indian Ocean Standard Net by *R.S. Africana II* at a grid of stations on the Agulhas Bank during 18 months were studied and compared with the hydrographical data taken at the same time; a few samples taken off the bank were used for comparison. Average monthly distribution over the bank and the time/space distribution at the fixed stations were studied for total biomass, Copelata, Chaetognatha, Copepoda, fish eggs and larvae. The main conclusions point at a high productivity of the Agulhas Bank water, frequent formation of patches that drift west and southwards, a small seasonal fluctuation of biomass, patchiness of Copelata distribution, a similarity in the distribution of total biomass with Copepoda and to a lesser degree with Chaetognatha, and a very strong seasonal variation of the frequency distribution of fish eggs and larvae. High productivity of the Agulhas Bank water is considered to be brought about by horizontal mixing caused by eddies, mixing of water masses and upwelling.

THE ocean at and around the southern end of Africa has raised much interest and speculations as well as many attempts at exploration of its peculiar features, particularly as a meeting place of the two great oceans, the Atlantic and the Indian, ever since the Portuguese first rounded the 'Cabo da Boa Esperanca' (Cape of Good Hope) and ventured into the Indian Ocean from the south-western approach. Thus the first descriptions of the cape and the coast further south-east to the "Cabo Agulhas" (Compass Cape) were described in the log books of Portuguese navigators and their Italian pilots, along with the currents, storms, anchorages and harbours. Not much information was added until Dietrich<sup>1</sup> studied in detail the Agulhas Current, and Deacon<sup>2</sup> analysed the data of the discovery. Methodical studies of the west and east coasts of South Africa were undertaken by the Division of Sea Fisheries of the Republic of South Africa and by the University of Cape Town<sup>3-7</sup>. After the pioneering work of Cleve<sup>8,9</sup> plankton studies on the Agulhas Bank were started only recently<sup>10,11</sup>.

The present study is part of a major effort towards the understanding of the oceans off South Africa, since the samples analysed are part of a larger series of samples taken at a grid of fixed stations on the Agulhas Bank visited at regular intervals by *R. S. Africana II*; hydrographical data were collected at the same time.

The object of the present investigation is to gain knowledge on the distribution of (i) total biomass throughout the year, (ii) copepods as they constitute the bulk of the zooplankton, (iii) Chaetognatha and Copelata as examples of animals placed at a high and at a low level in the trophic web, and (iv) fish eggs and larvae, due to their applied interest. A rough analysis of distribution in relation to environmental factors is also attempted.

### Materials and Methods

Plankton samples (205) collected by *R.S. Africana* in the Agulhas Bank area during the International Indian Ocean Expedition were entrusted to IOBC by the Division of Sea Fisheries of the Department of Commerce and Industries of the Republic of South Africa for sorting and basic studies. Samples were collected monthly from January 1964 to June 1965; samples collected in July 1963 were also available. The samples were taken with the Indian Ocean Standard Net hauled vertically through the whole water column over the bank and through the upper 200 m beyond the shelf. The plankton volume was measured at IOBC by displacement, and the values were reduced to 100 m<sup>3</sup> and plotted at monthly intervals per station. The mesh width of the net was 0.33 mm. Considering the selectivity effect of the net it is expected that zooplankton biomass measured on samples taken with other nets, having wider or narrower mesh width, will produce different figures and different patterns of biomass distribution. Thus it must be borne in mind that this paper refers only to the distribution of the smaller zooplankton<sup>12</sup>.

The values shown on the figures for the categories other than biomass were obtained by sorting out and counting the specimens of a subsample and then estimating the number present in the total sample. The size of the fraction sorted varied with the size of the plankton sample. The size of the fraction was never smaller than 3-4 ml but when size of the whole sample was less than 3-4 ml, the whole sample was taken as the fraction. Splitting was done with the Folsom plankton splitter.

The stations plotted on the figures are all shown at the same point; in reality, the position occupied by the ship was not exactly the same during different cruises. The lines of equal density on the figures

are all drawn by visual estimation after graphic interpolation.

The area of this study is limited by the 20°E and 22°E meridians by the African land mass to the north and roughly by the 37°50'S lat. parallel to the south. This area extends to the south slightly beyond the shelf; it lies north of the subtropical convergence and receives a minor portion of the Agulhas Current that flows westward into the Atlantic along the edge of the shelf while its major stream is deflected eastwards back into the South Indian Gyre. The first 5 stations of each section, starting from the shore, were worked monthly, the two outer ones beyond the shelf, only once per quarter (weather permitting), thus only few samples were available from off the shelf.

The instability of the current pattern and the formation of eddies moving away from the main stream is a known feature of the area.

## Results

**Total biomass**—The pattern of total zooplankton volume distribution or biomass (Figs. 1 and 2) shows that the higher standing stock is in the eastern part of the area from where plankton rich waters flow over the bank. In April, May, July, September and November the lines of equal density of 5, 10 or 15 ml/100 m<sup>3</sup> were found to run north-south with higher density to the east. The only exceptions were June and December 1964 with a slight and negligible concentration at the western end of the area. In February and March 1965, patches with densities higher than 25 ml/100 m<sup>3</sup> and up to 30 ml/100 m<sup>3</sup> were formed over the shelf at 40 to 50 naut. mile offshore; the February 1965 patch was already being formed in January and was still present in March 1965 (no data for March 1964). In August and October 1964 there was a great increase in plankton volume reaching densities higher than 25 ml and 30 ml/100 m<sup>3</sup> respectively along the coast with lines of equal density running parallel to the coast with decreasing values southwards. In July 1963 a moderately high value patch with over 18 ml/100 m<sup>3</sup> was present at the edge of the shelf and in June 1965 another patch with density higher than 10 ml/100 m<sup>3</sup> was being formed on the shelf, near to its edge. In both cases low plankton density water separated these offshore patches from inshore waters.

The formation of patches is very characteristic and their shape suggests that they may often be related with eddies that are known to be formed over the bank; from the main patches, smaller ones seem to branch off and drift away (Figs. 1 and 2). Another salient feature is the occurrence of abrupt and major changes in population density. The maximum values closely approximate the highest found in the Indian Ocean at scattered points and off the Saudi Arabian coast, where over 40 ml/standard haul (193 m<sup>3</sup> water filtered) were found<sup>13</sup>. Fig. 2A shows the average plankton biomass variation on the shelf throughout the period of sampling.

**Copelata**—A study of the distribution and abundance of the Copelata (Figs. 3 and 4) was undertaken considering the group as a single ecological category because all the species are nannoplankton feeders. A detailed study down to species level is under way. Fluctuation of abundance of the Copelata was very great and there were months when most stations had none or very few only (Fig. 4; July, August

and September 1964). Thus in winter (August and September 1964) there were none, while in October of the same year they were still very scarce. Peaks were found in January (more than 800/100 m<sup>3</sup> at temperature higher than 21°C), March (more than 800/100 m<sup>3</sup> at temperature higher than 21°C), April (more than 1600/100 m<sup>3</sup> at temperature higher than 21°C), and May (more than 800/100 m<sup>3</sup> at temperature higher than 18.5°C). Fig. 4A shows average frequency over the bank. Over the bank high density was associated with warm waters, but warm waters were not the only cause of their abundance since they were not invariably present in great numbers when temperature was high and they were not found to be abundant in the warm waters off the shelf in July, the only month when Agulhas Current water was sampled and for which data were available. The great abundance in inshore stations was probably related to particular abundance of food organisms.

The pattern of the distribution suggested that these nannoplankton feeders during the period of sampling came into the area from the east. In 1964 a dense patch came in February, while in 1965 the patch was larger, denser and lasted longer.

The patches moved westward while the population density decreased, presumably due to predators, decrease of food availability and dispersal. Another large patch with very high numbers was found in March (1965) near the coast and it moved southward while still increasing, in size, then westwards, as the density decreased.

It would be interesting to correlate the distribution and abundance of Copelata to nannoplankton abundance.

**Chaetognatha**—The Chaetognatha (Figs. 5 and 6) of this collection were sorted as a group, therefore, no analysis of the distribution or autoecology of the single species is considered here. The study of the spatial and temporal distribution of the Chaetognatha is considered to be interesting from the ecological point of view because all the species are throughout their life cycle exclusively carnivorous and obtain their food by active hunting, but species of different individual size and different age groups probably feed on differently sized prey.

The total number of Chaetognaths was high but did not reach values equal to the highest, density areas in other places of the Indian Ocean<sup>14</sup> such as Gulf of Aden and off Somalia, where peak densities higher than 6200 specimens per standard haul (upper 200 m layer, a volume of 193 m<sup>3</sup> of water filtered) were found. While the highest values on the bank were 1600 spec/100 m<sup>3</sup>, the IOBC Plankton Atlas<sup>15</sup> shows maximum values of 400-1599 spec./193 m<sup>3</sup>, for the same area.

The pattern of distribution (Figs. 5 and 6) of the Chaetognatha was patchy with steep gradient and numbers vary abruptly also in time. There was a similarity between the patterns of distribution of Chaetognatha and those of total biomass, allowing for a certain delay in time and space. Increase of Chaetognatha abundance also seems to come from the east and patches drift westwards and southwards. They may be relatively abundant even beyond the edge of the shelf.

Fig. 6A shows the average frequency distribution over the shelf: the trend shows pronounced variations of abundance.

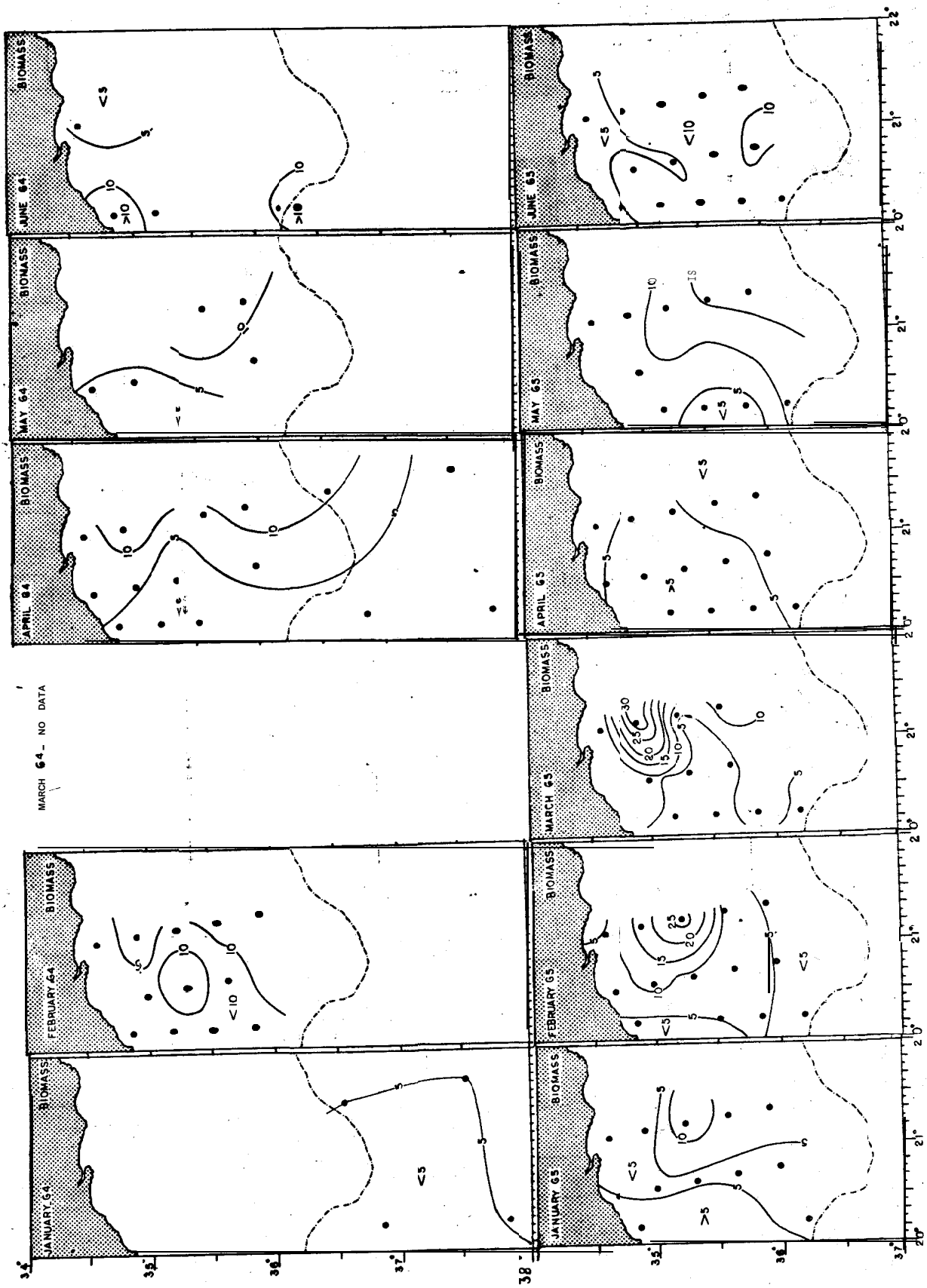


Fig. 1 — Monthly distribution; of total biomass measured as displacement volume (ml).

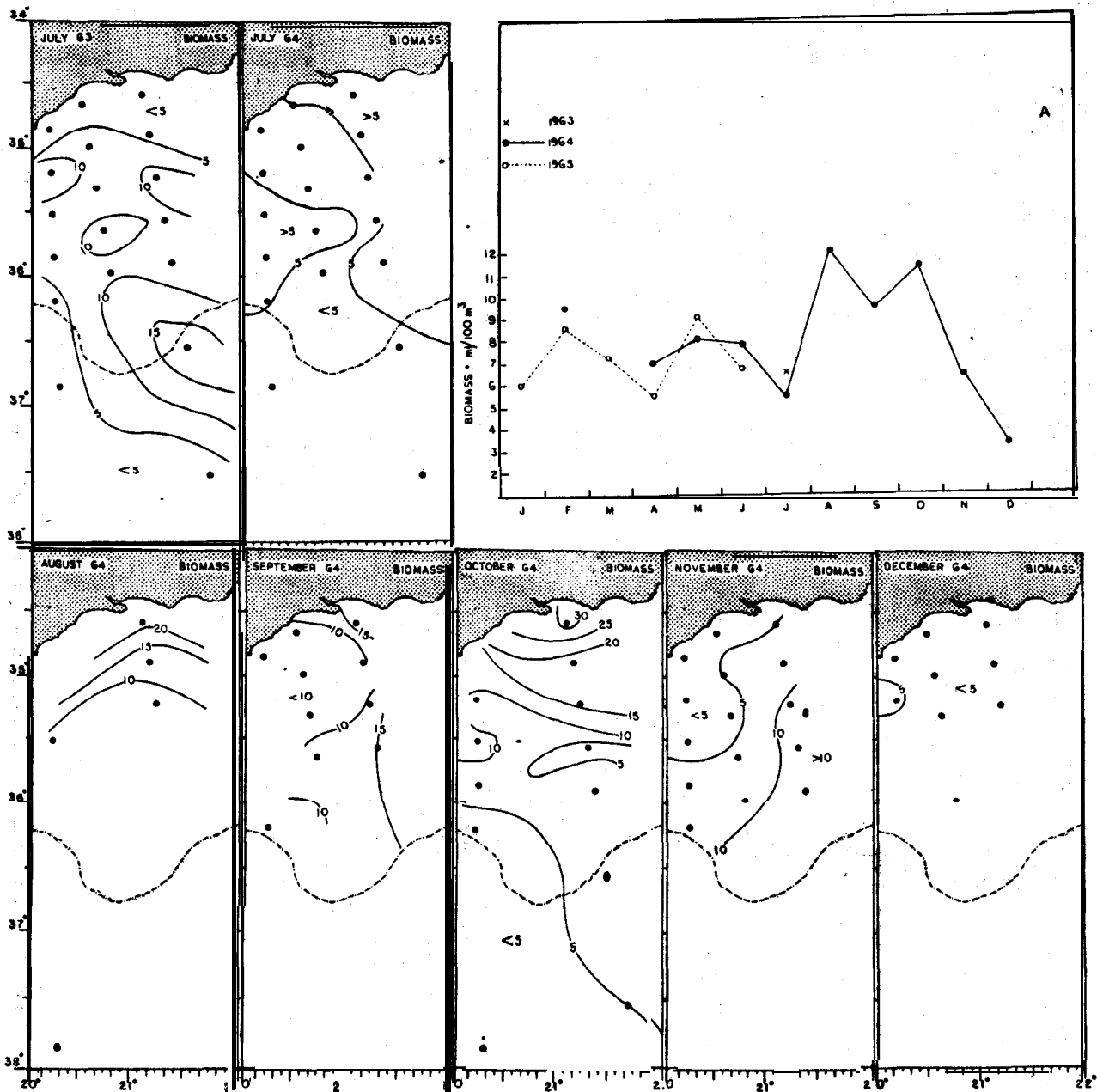


Fig. 2 — Distribution of total biomass and (A) average biomass volume over the shelf

*Copepoda* -The study of the distribution of the copepods, assessed as total number of specimens/100 m<sup>3</sup>, was made because the copepods represent from 60 to 90% of the total biomass measured as displacement volume. They are interesting as an ecological category of fundamental importance in processes of energy transfer because they form the bulk of the zooplankton that is consumed by the primary and secondary carnivores. They do not, as a category, represent a definite level in the food web since phytophagous, carnivorous and omnivorous species are all represented in the category and are present in different percentages at different times and places.

It is not surprising to find that the patterns of distribution (Figs. 7 and 8) of abundance of copepods correspond rather closely to those of the total

biomass. Fig. 8A shows average frequency distribution over the shelf. The differences in the details of the curves of equal density (Fig. 8A) may be due to several factors: (i) Copepods are measured as number of individuals while biomass is measured as volume, therefore, the two measures are only approximately comparable. (ii) A large number of small adults or of small developmental stages will rank high in copepod counts while their volume may be rather insignificant, conversely a small number of large copepods may sum up to a large volume. Thus the abundance measured as numerical distribution is dependent on the species composition. (iii) Significant bias may have been introduced by the sampler since the plankton that has been measured represents only a fraction of the association at sea, the very small plankton being lost

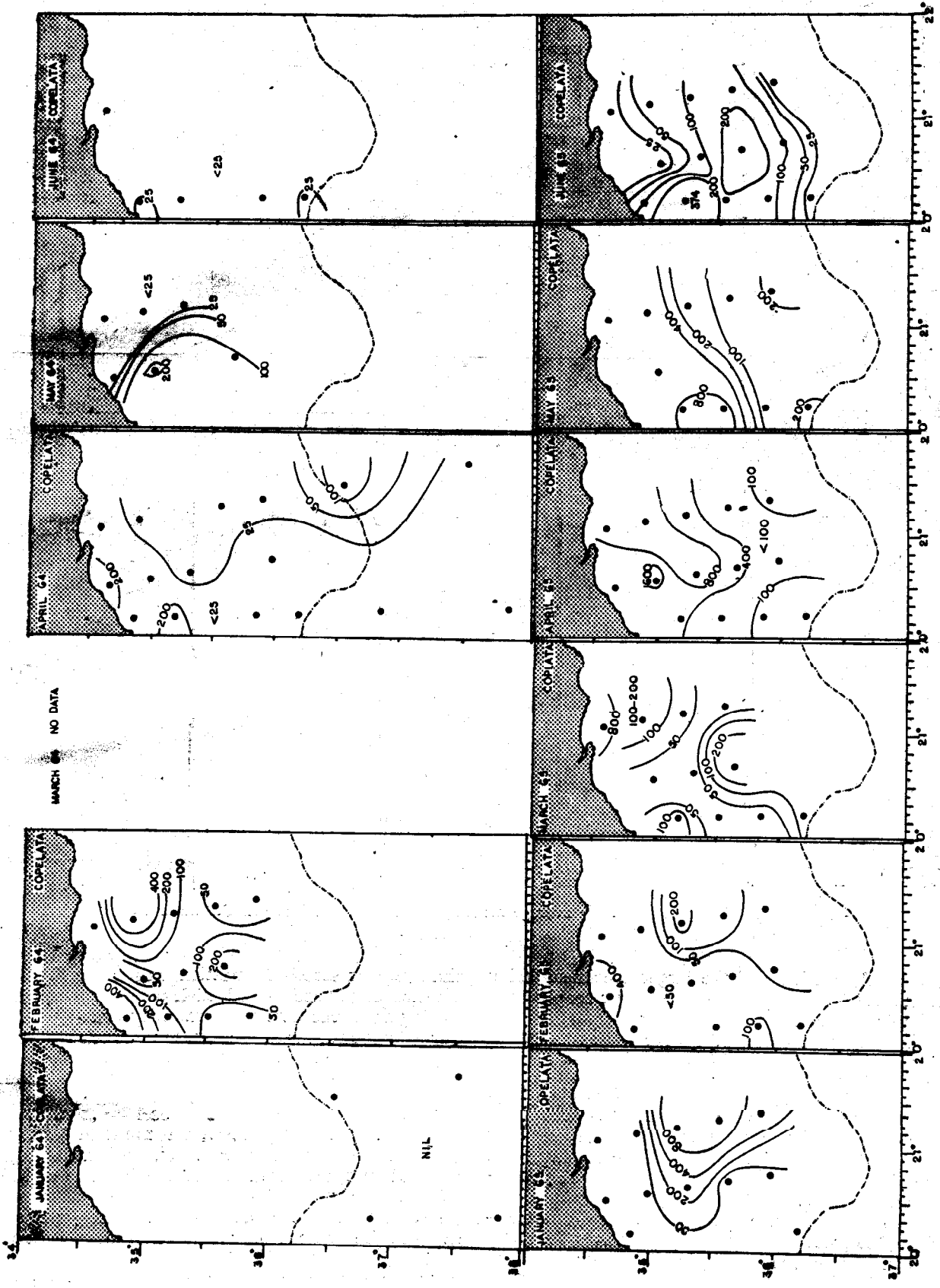


Fig. 3 — Distribution of Copelata as number of specimens in 100 m³ of water filtered

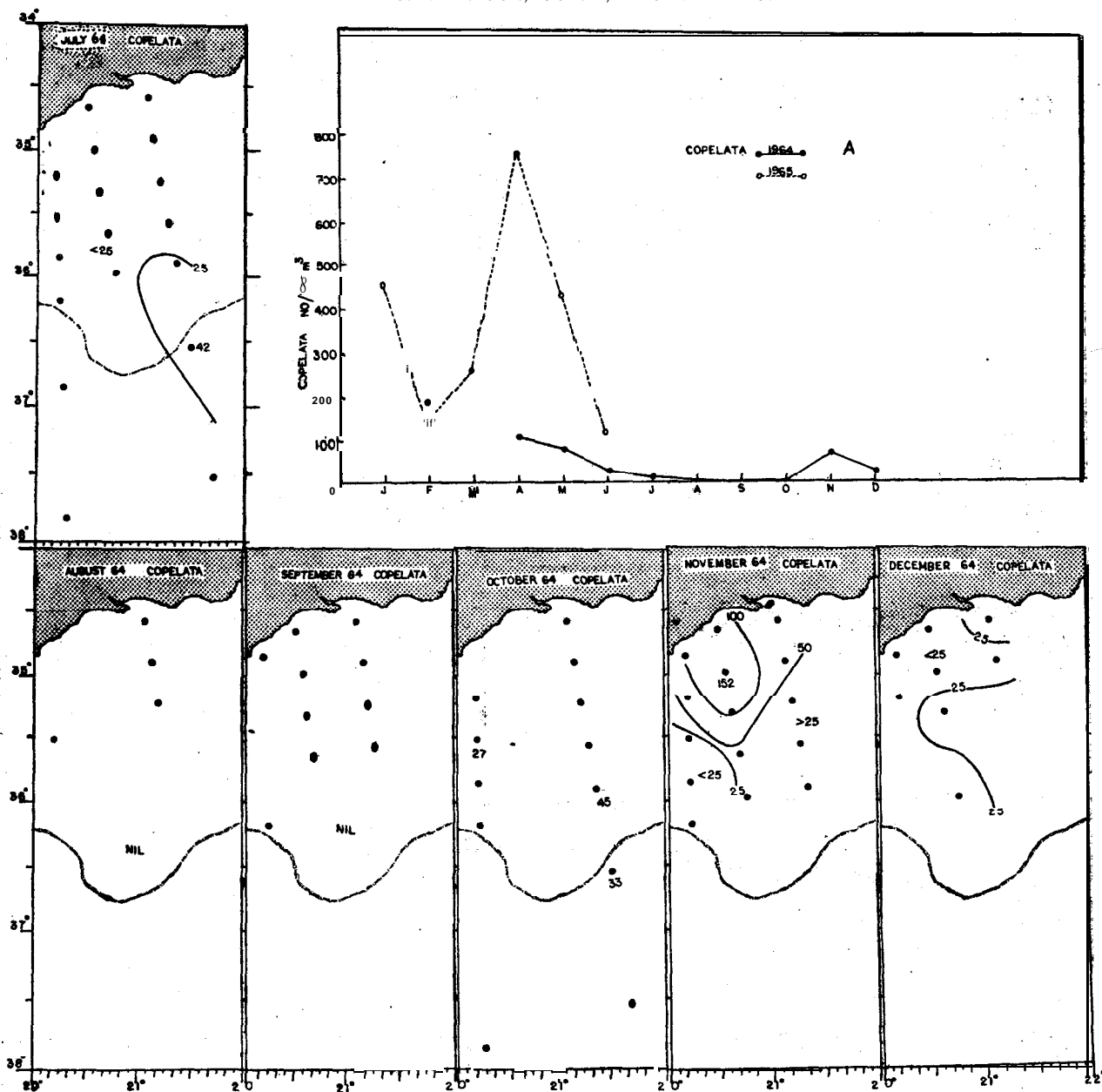


Fig. 4 — Distribution of Copelata and (A) average monthly numerical abundance in the water over the shelf

through the meshes and the larger specimens being selected against, like for instance larger zooplankton and micronekton.

The highest density of copepods was found in winter (July to November) with density ranging from over 25000 to over 50000/100 m<sup>3</sup> and in summer (January to March), with patches that had more than 50000/100 m<sup>3</sup>. April, May and June were poor months in 1964 and in 1965, except for a patch with more than 50000/100 m<sup>3</sup> in May 1965. The highest value found was Of 116307 spec./100 m<sup>3</sup> in October 1964.

In some cases dense biomass patches did not correspond to great numbers of copepods as in February 1965, and a copepod patch in November 1964 and another in May 1965 with more than 50000/100 m<sup>3</sup> were found where only mediocre biomass was present.

Again just as for the distribution of the biomass and of Chaetognaths, copepods abundance rather

than regular seasonal variation was shown by the appearance of patches with high population density, coming from the east and gradually drifting westwards or southwards. Many such patches would perhaps be related to the formation of eddies.

**Fish eggs**—Fish eggs were caught throughout the year (Figs. 9 and 10), but the principal spawning season was summer and December through February. Maximum density was found in January 1965 with 7060 eggs/100 m<sup>3</sup> at 34°37'S lat. 20°27'E; moderate patches were found also in September 1964.

Because eggs develop in a few days, their presence as such in the plankton was ephemeral and sampling being done only once a month, no details could be given here.

As far as spawning areas were concerned, there seemed to be two main spawning grounds, one inshore, north of 35°S lat. and a secondary one towards the middle of the bank at about 35°30'S lat.,

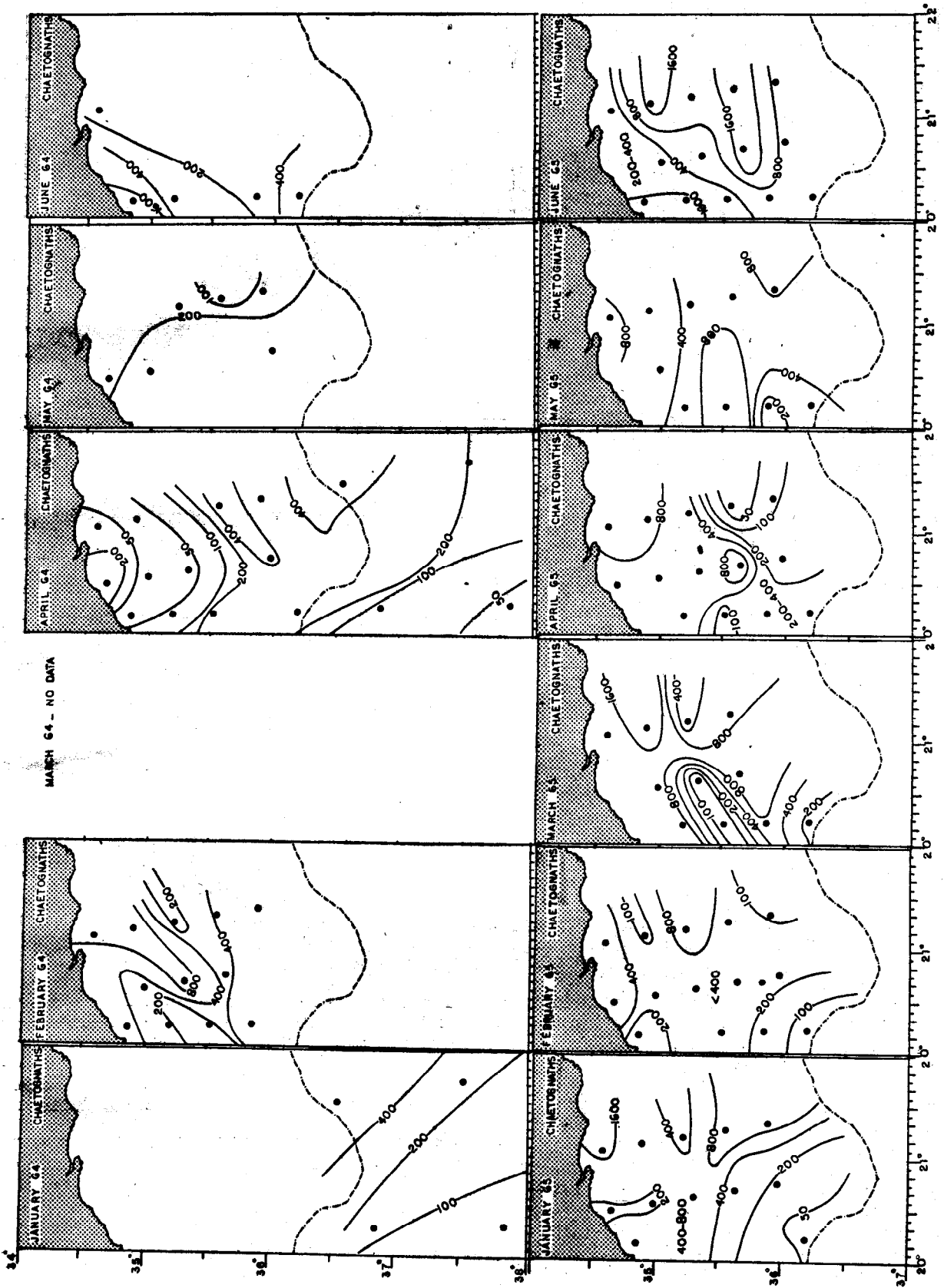


Fig. 5 — Distribution of Chaetognatha as number of specimens in 100 m<sup>3</sup> of water filtered

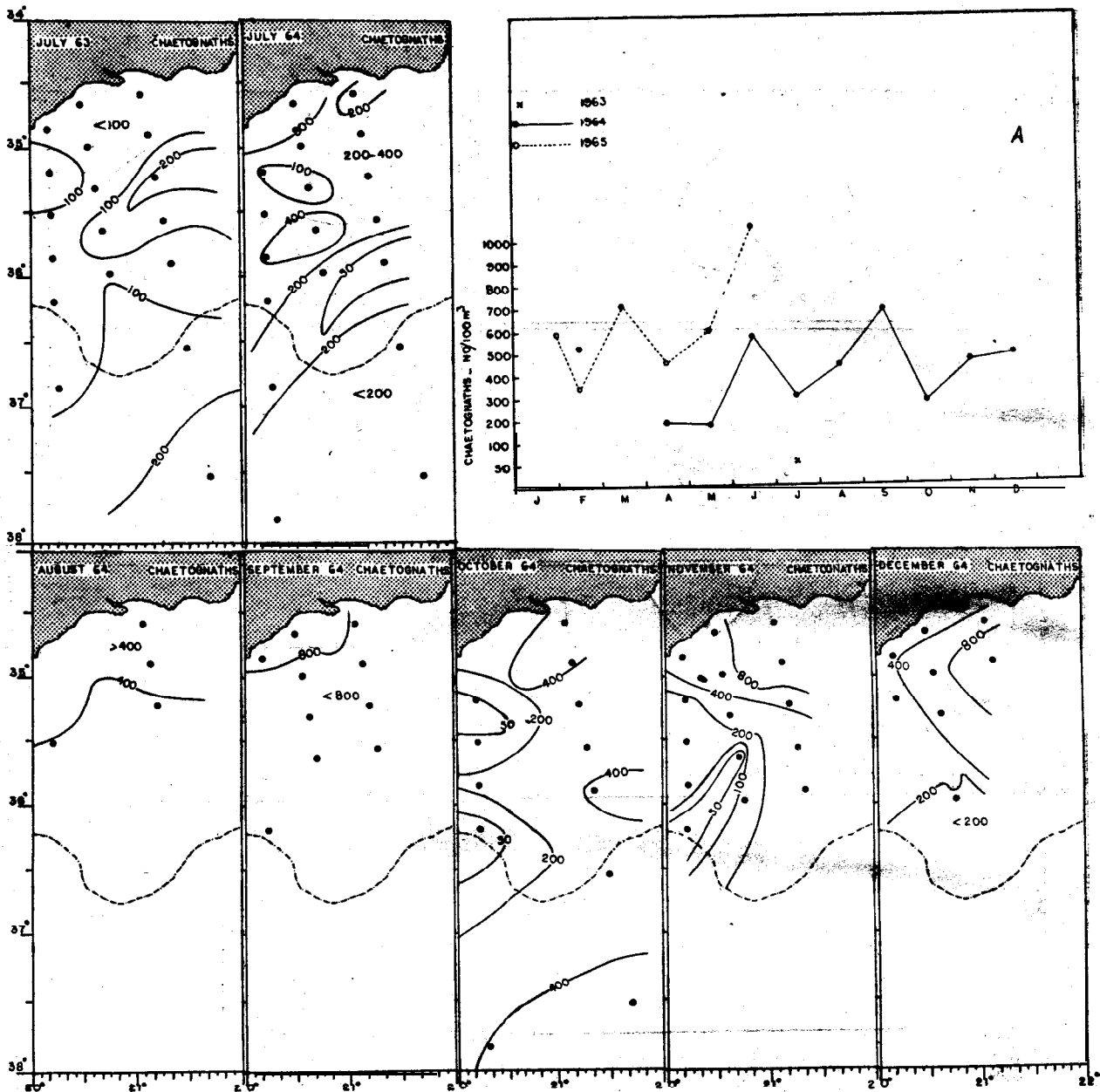


Fig. 6 — Distribution of Chaetognatha and (A) average monthly numerical abundance in the water over the shelf

if indeed they may be called separate. A third spawning ground could have been found just south of the bank's edge, but samples were insufficient. The shape of the egg patches revealed the trend of the currents. Fig. 10A gives the average frequency distribution over the bank.

It is easy to identify the eggs of *Engraulidae* and the species present is presumably *Engraulis japonicus*. The patches show that the eggs of this species appeared in the plankton in September, October and December 1964 to February, 1965. There is a sample in June in what we consider to be warm Agulhas Current water, although the penetration of warm South Atlantic Surface Water in the area is not to be excluded. The peak of abundance is in January-February. Surface temperature at the stations, where *Engraulis* eggs were found, is given in Table 1.

**Fish larvae**—The pattern of spatial and seasonal distribution (Figs, 11 and 12) of the fish larvae was very similar to that of the fish eggs, as might be expected. Peaks of abundance and areas of maximum numbers were the same except for some delay in time and greater spreading in space of the larvae

TABLE 1 — SURFACE TEMPERATURE AT STATIONS WHERE *Engraulis* EGGS WERE FOUND

Period	Temp., °C
September 1964	14.89
October "	15.64; 16.64; 18.25
December :	17.89; 17.89; 18.60; 19.07; 19.27
January 1965	20.38; 20.71; 20.79
February "	21.51; 21.76
June "	20.16



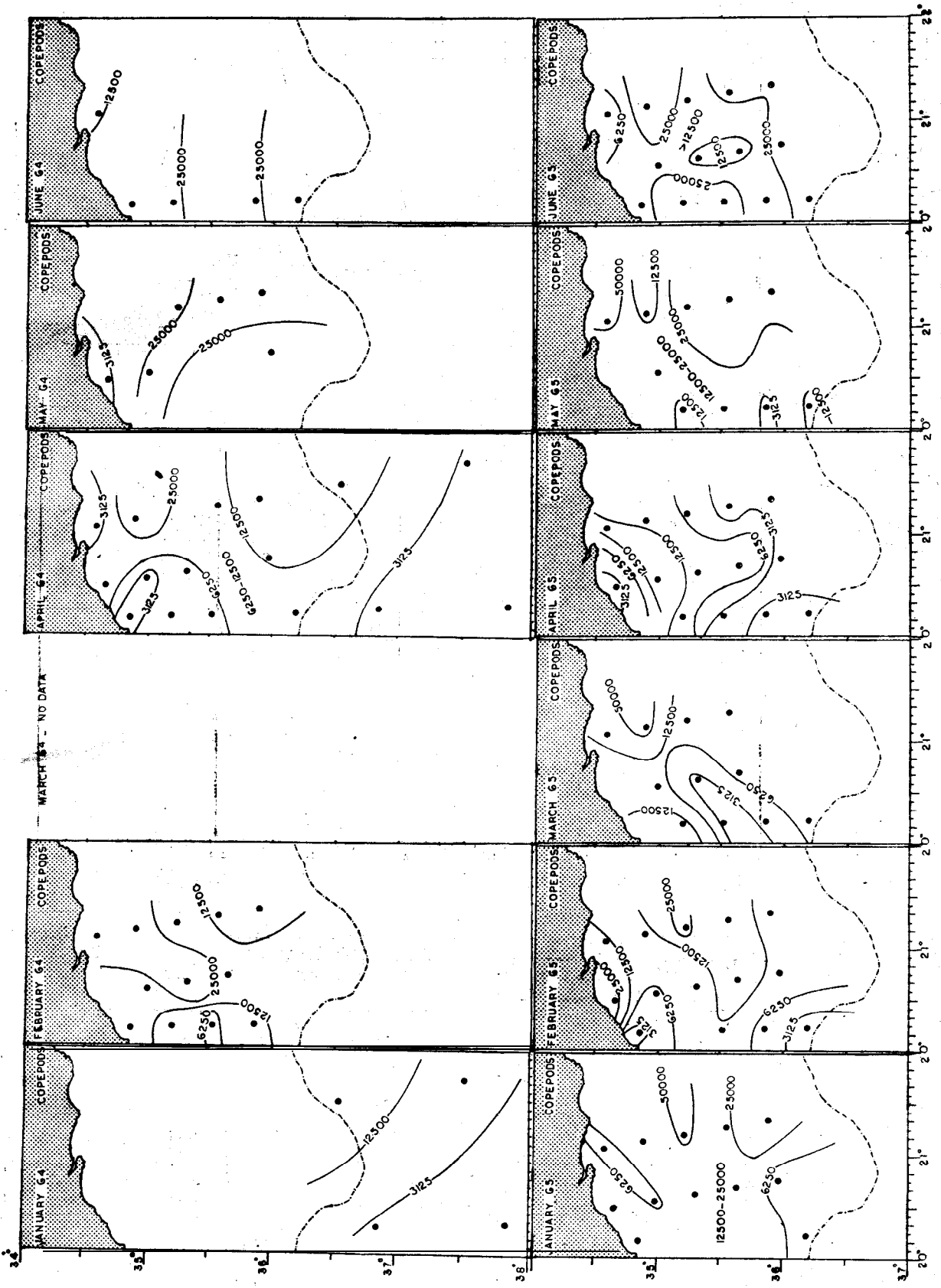


Fig. 7 — Distribution of Copepoda as number of specimens in 100 m³ of water filtered

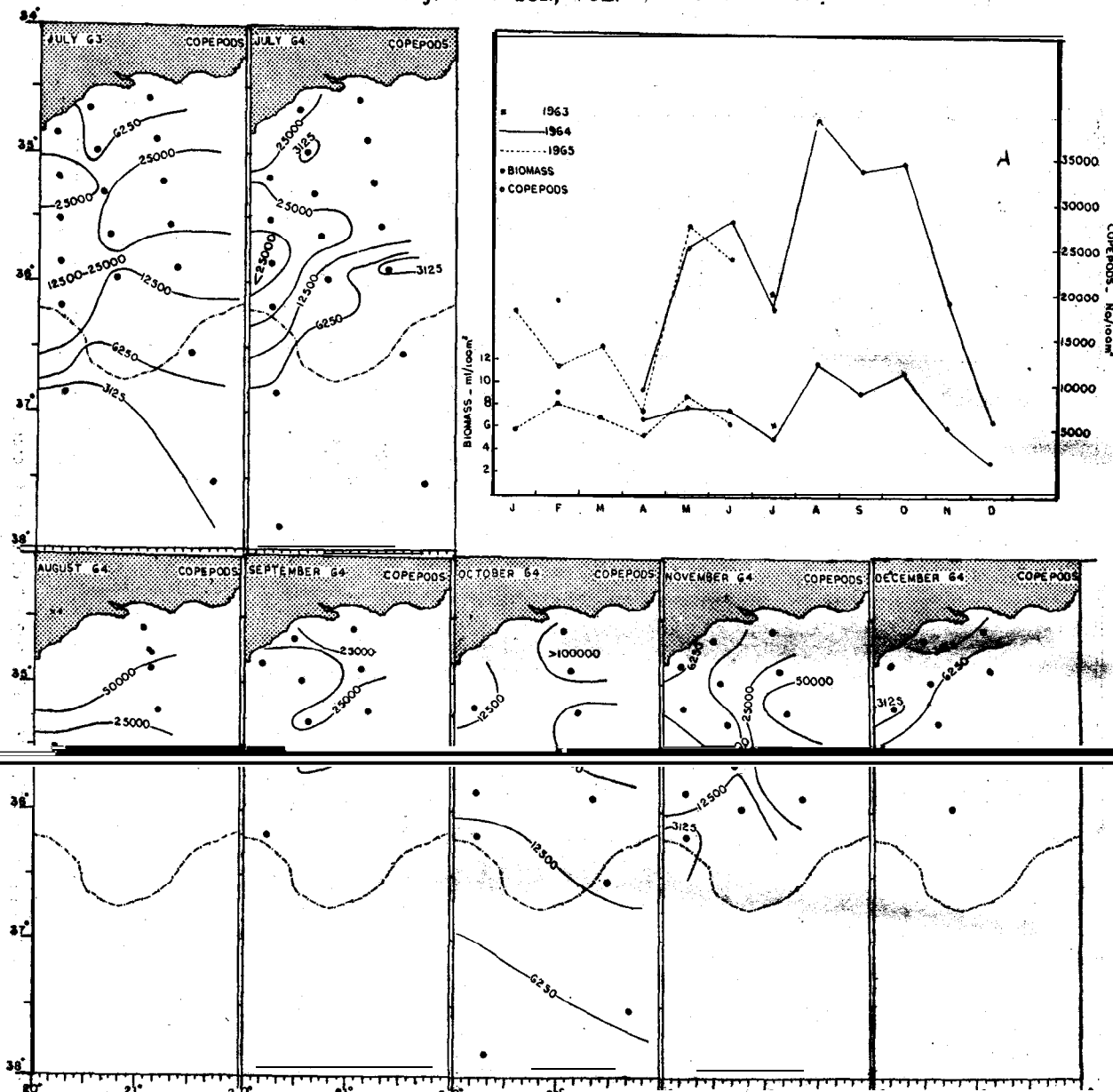


Fig. 8 — Distribution of Copepoda and (A) average monthly numerical abundance in the water over the shelf

due to drifting. Maximum number of fish larvae was 1040, at the same station where maximum number of eggs was found. Fig. 10A gives the average frequency distribution, over the bank. The larvae of *Engraulidae* were found from October 1964 to June 1965. Surface temperature of the stations, at which larvae were observed, is given in Table 2.

**Distribution and abundance in relation to hydrography** — The area covered by the present series of samples was restricted to a narrow strip on the Agulhas Bank, in addition to a few samples from just off the shelf. The hydrographic data of the cruises were made available by the South African Division of Sea Fisheries and judging from the sigma-t no sample in this series was taken from the core of the Agulhas Current and only very few come from the transition zone.

The whole area lies north of the subtropical convergence and mostly north of the warm waters of the Agulhas Current that flows in a south-westerly direction. From the data it appears that the water

over the bank was fairly stable during the 18 months of sampling, with an isothermal and isohaline surface layer during winter that was heated

TABLE 2 — SURFACE TEMPERATURE OF STATIONS AT WHICH LARVAE OF ENGRAULIDAE WERE OBSERVED

Period	Temp., °C
October 1964	17.53
November "	17.49; 17.50; 17.66
December "	19.15; 13.82; 19.60
January 1965	20.79; 21.05; 21.47; 20.60; 21.53; 20.35; 21.25
February* "	21.32; 21.34; 21.84; 21.99; 21.51; 21.95; 21.53; 21.28; 21.33; 21.96
March "	21.07; 20.68
April "	19.20; 18.77; 20.98; 20.95
May "	18.94
June "	19.78

\*Temperatures given for February 1964 also.

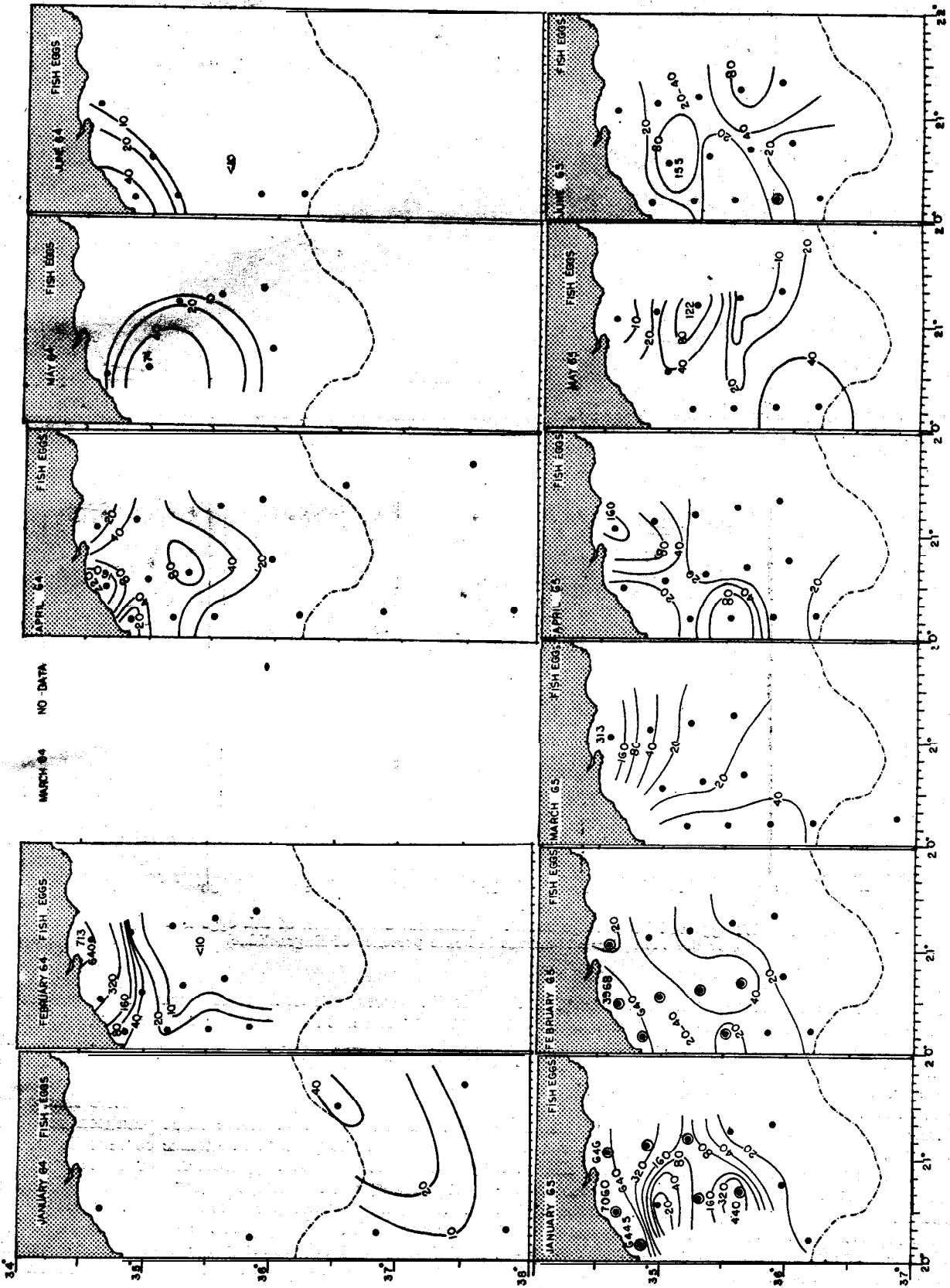


Fig. 9 — Distribution of fish eggs as number of specimens in 100 m<sup>3</sup> of water [Circled stations indicate eggs of Engraulidae]

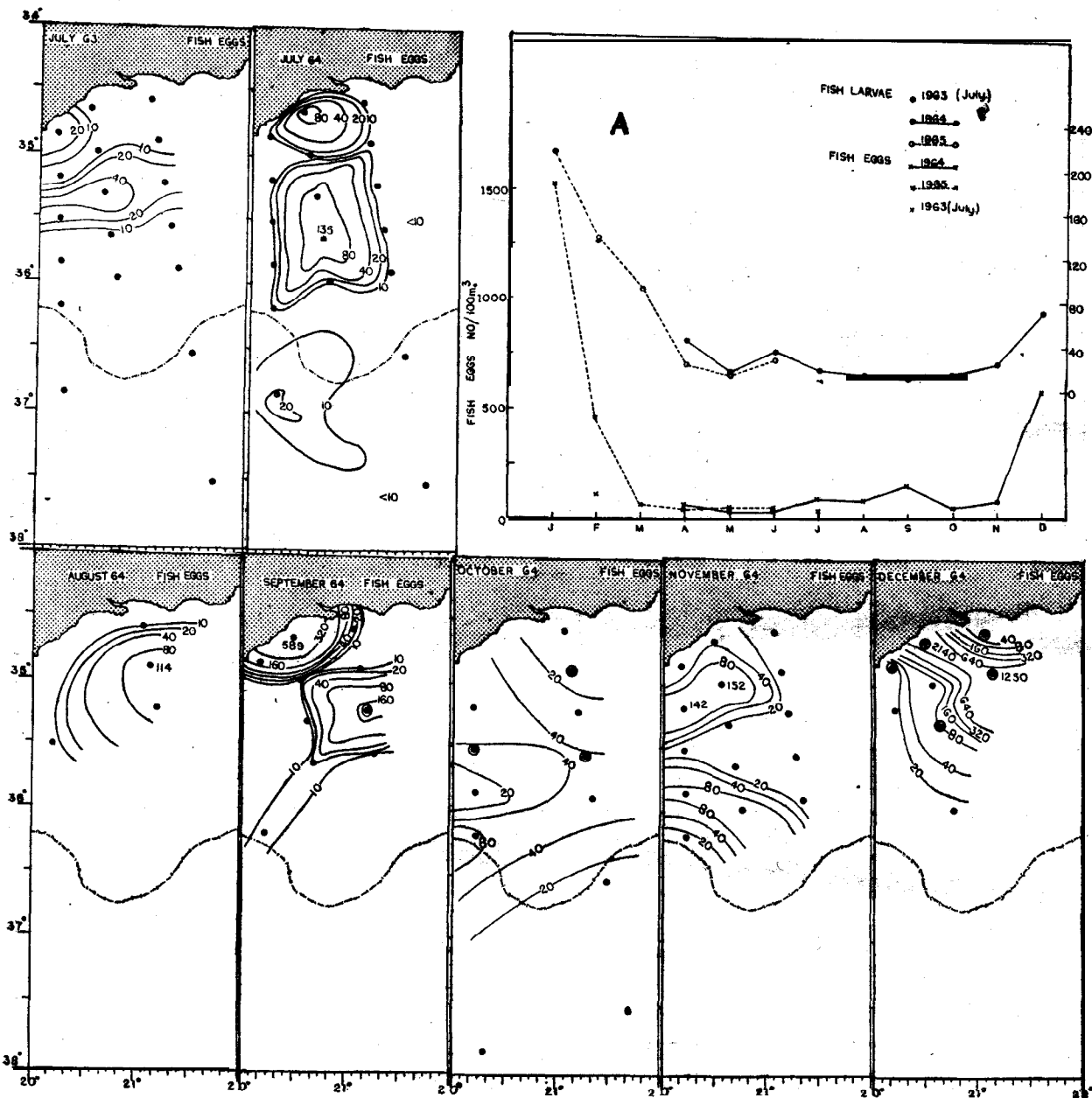


Fig. 10 → Distribution of fish eggs and (A) average monthly numerical distribution of fish eggs and larvae in the water over the shelf [Circled stations indicate presence of Engraulidae]

in summer to temperature as high as 21.6°C. The SW face temperature in winter over the bank was as low as 14.7°C. A thermocline was always present, more steep in winter. It was found at 30-50 m depth or, more often, at 50-75 m. The water below the thermocline was Indian Ocean Central Water formed by sinking at the subtropical convergence, or Atlantic Ocean Central Water which upwells over the shelf. Off the edge of the shelf it is found at about 200 m depth. The southernmost samples in this series come from somewhat mixed Agulhas Current waters, with a lower sigma-t higher temperature and slightly higher salinity than the Agulhas Bank waters. At stations near to the coast in summer due to direct and local heating, the sigma-t may fall to values lower than those of the Agulhas Current, as low as 24.41. Surface layer salinity is throughout the year above 35.2‰ while

Indian Ocean Central Water was found to have salinity lower than 35.0‰ or only slightly higher with temperature lower than 10-12°C. Agulhas Current water has slightly higher salinity, above 35.35‰.

The work of Duncan and Nell' indicates that over the bank in the area where these plankton samples were taken, the pattern of surface currents is mixed usually not very strong, westerly or easterly drifts may occur, with patterns changing in the different seasons, and eddies are often formed. Their work also shows the upsloping of the sigma-t, 26.2 surface over the bank in January.; the 10-11°C isotherm is usually found at a depth between 50 and 75 naut. mile offshore and 30-50 naut. mile at the inshore stations. The upwelling of cold deep water over the bank appears to be originated mainly by the main feature. of the area, i.e. the Agulhas Current

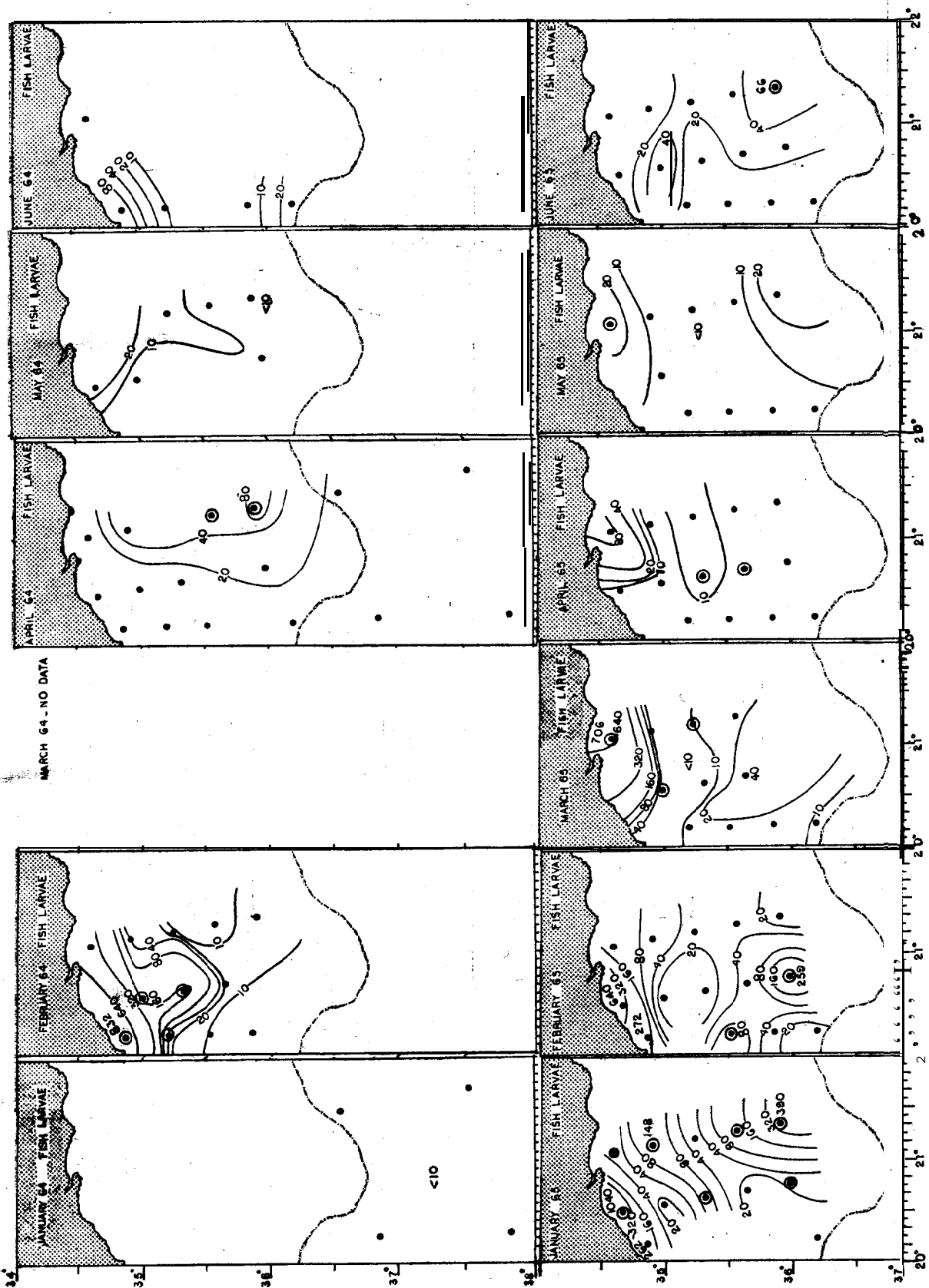


Fig. 11 — Distribution of fish larvae as number of specimens in 100 m<sup>3</sup> of water [Circled stations indicate presence of Engraulidae]

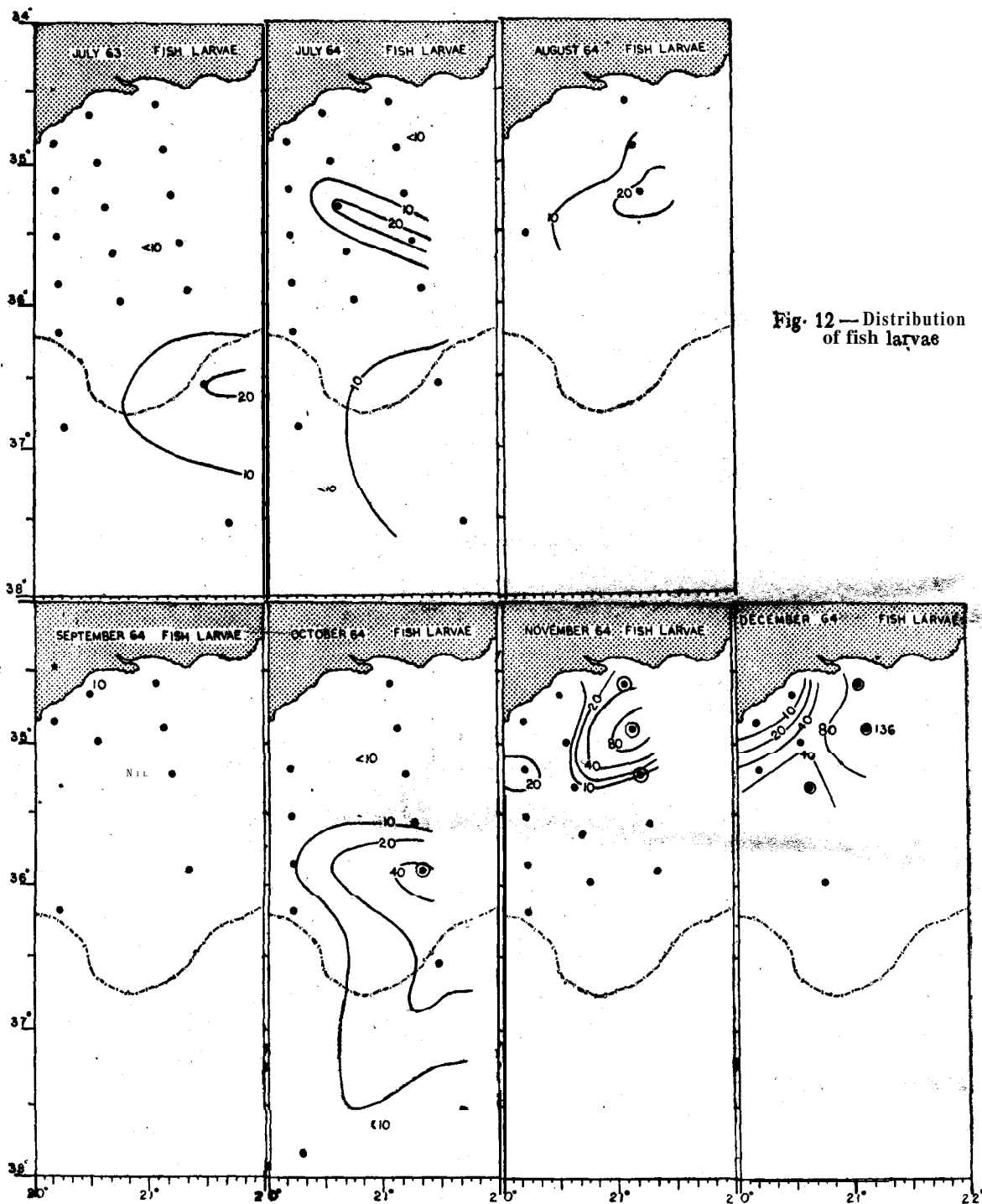


Fig. 12—Distribution of fish larvae

running offshore and the resultant upward tilting of the thermocline coastalwards.

Analysis of biomass distribution in relation to environmental data allows the following conclusions :

(1) The average plankton biomass in the warm offshore transition area where there is mixed Agulhas Current water, was 1.62 ml/100 m<sup>3</sup> in July 1963 and July 1964 while the average on the bank during same months is 6 ml/100 m<sup>3</sup>. Data are insufficient for similar comparisons in the other months, however, Fig. 2A shows fluctuation of monthly means of biomass on the Agulhas Bank water with an overall average of 7.7 ml/100 m<sup>3</sup>.

(2) Total biomass is rather high on the average and in addition very dense and large patches are formed occasionally (Fig. 1; February and March 1965), they may last for 1 month or more. There appears to be no immediate correlation between the formation of patches and upwelling.

(3) The pattern of some of the high density biomass patches suggests that eddies, known to be formed over the bank, may be related to increased zooplankton biomass. The admixture of Atlantic water and of Agulhas Current water at the periphery of the bank may act as seeders of 'different populations to bank water where they multiply inten-

sively due to the high primary productivity of the bank water. De Decker<sup>10</sup> found that copepod species of Atlantic origin flourish over the bank.

Longer time series samples over a wider strip of the bank and extending south to the core of the Agulhas Current are highly desirable in order to assess the distribution and production of the plankton over the area. The data suggest that the high production well known for the Agulhas Bank is brought about by turbulence, horizontal mixing by eddy formation and upwelling inshore and offshore.

### Discussion

This 18-month long survey indicates that the plankton of the water of the Agulhas Bank is rich in terms of biomass per unit volume of water. The monthly average of biomass over the shelf fluctuates from 3.1 ml/100 m<sup>3</sup> in December to 12 ml/100 m<sup>3</sup> in August, the annual average being 7.7 ml/100 m<sup>3</sup>. The seasonal variation indicates increase in the winter months. While the fluctuation of average total biomass is not very great, the variation in density of the plankton per unit volume of water is well marked by steep gradients due to the formation of localized dense patches, a common occurrence in the area.

Judging from the hydrographical data the Agulhas Bank water appears to be rather stable; nevertheless we find in this area the influence of Indian Ocean Central Water (IOCW) or Atlantic Central Water (ACW) upwelled over the bank, of Agulhas Current water running along the edge of the shelf and of Atlantic waters meeting the impact of Indian Ocean waters. By turbulence, by horizontal mixing due to eddies and by upwelling they tend to enrich the Agulhas bank waters.

The bulk of the plankton is represented by Copepoda and they vary in a manner similar to the variation of the total biomass. Density of the patches reaches values greater than 50000 spec./100 m<sup>3</sup>, these values are near to the highest values found in the Indian Ocean during the International Indian Ocean Expedition.

Except for a marked preference for warm waters, the distribution of the Copepoda is irregular in time and space, with formation of relatively dense swarms. The sampling of the Copepoda, however, is quantitatively biased due to the relatively wide mesh of the net; the distribution of the Copepoda is probably influenced by the formation of nanoplankton patches. The frequency distribution in corresponding months of successive years shows no similarity.

Highest density of Chaetognatha approximates but does not equal the highest numbers found in the Indian Ocean during the International Indian Ocean Expedition.

Fish eggs and larvae have a similar distribution with high densities in the winter months. The eggs and larvae are presumably *Engraulis japonicus*, an important percentage of the total number of eggs and larvae. Spawning grounds are indicated on the maps. Spawning of Engraulidae over the bank takes place in a wide range of temperature from 14.9° to 21.7°C, during a long season, from September to February.

It seems likely that the productive Agulhas Bank water is enriched by more than one mechanism, namely by the frequent formation of relatively small eddies and consequent horizontal mixing, by near-shore turbulence and by upwelling inshore and offshore.

### Acknowledgement

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